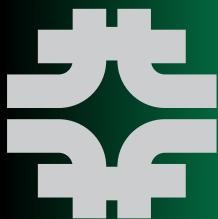


CTEQ task force on W and Z boson physics

J. Huston, Pavel Nadolsky (convener), J. Pumplin, D. Stump,
W.-K. Tung, C.-P. Yuan, ...

Objective:

- ✓ high-precision model for W and Z boson observables
- ✓ predict uncertainties for the Run-2 measurement of
 - ◆ W and Z total cross sections,
 - ◆ M_W ,
 - ◆ p_T distributions,
 - ◆ ...



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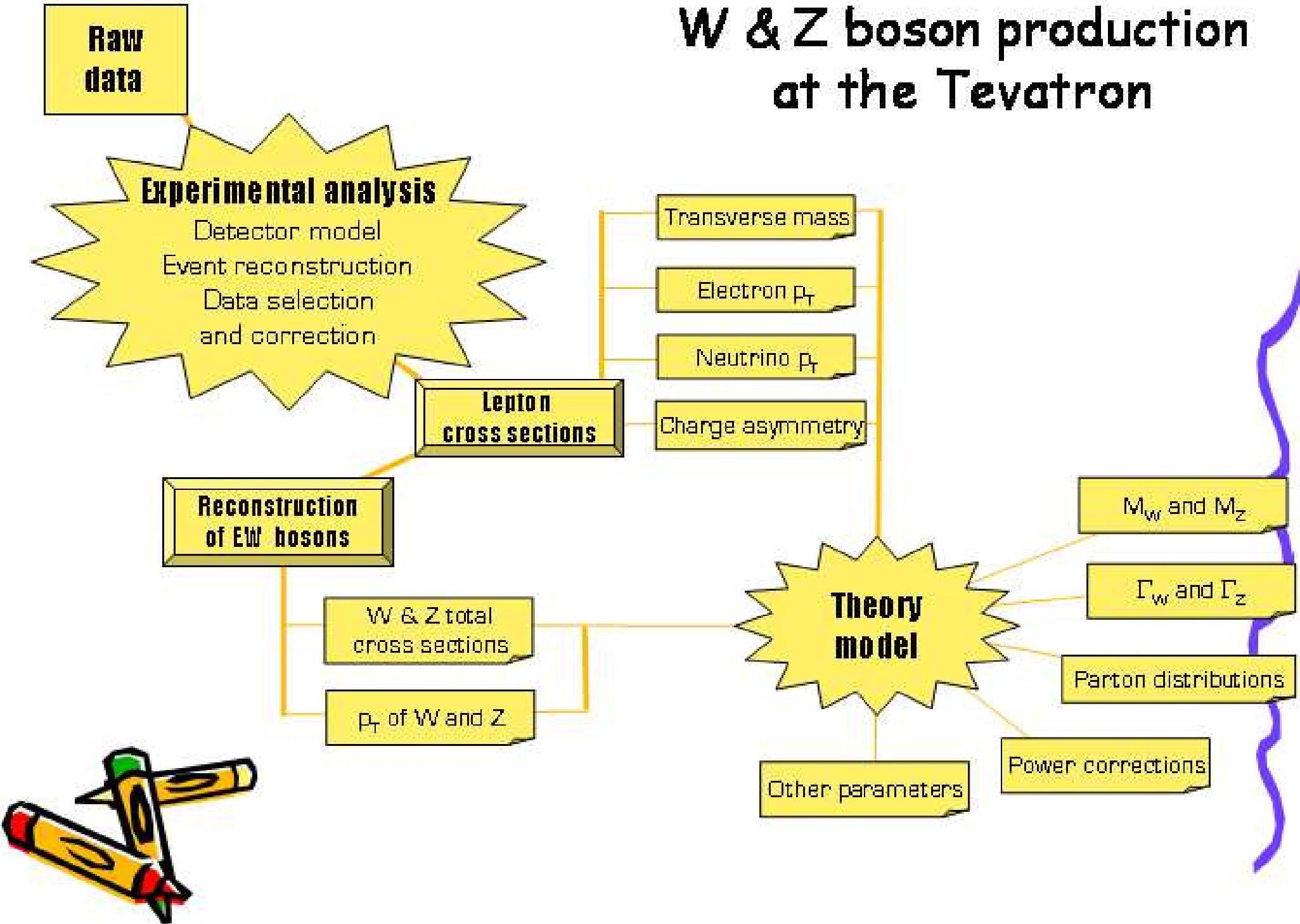
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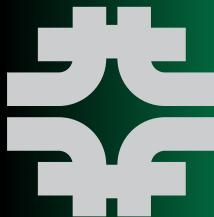
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- ✓ predict uncertainties for the Run-2 measurement of
 - ◆ W and Z total cross sections,
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 - ◆ ...

Collaboration with experimental groups

☞ decide on contact persons from CDF and DØ

W & Z boson production at the Tevatron



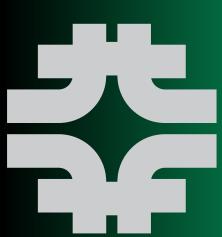


Variations in the fitted M_W in Run-1 (in MeV)

	Central electrons ($ y_\ell \leq 1$)			Forward electrons ($1 \leq y_\ell \leq 2.5$)		
Source	δM_W (m_T)	δM_W (p_T^e)	δM_W (p_T^ν)	δM_W (m_T)	δM_W (p_T^e)	δM_W (p_T^ν)
statistics	70	85	105	107	128	159
$p_T(W)$ spectrum	10	50	25	22	37	44
MRSR2	5	26	3	-11	-21	-43
MRS(A')	-5	16	-31	-7	-43	-19
CTEQ5M	-8	6	-22	14	9	-17
CTEQ4M	10	11	-18	1	-21	22
CTEQ3M	0	64	-9	13	30	28
(Many) other

DØ Collaboration, Phys. Rev. D62, 092006 (2000)

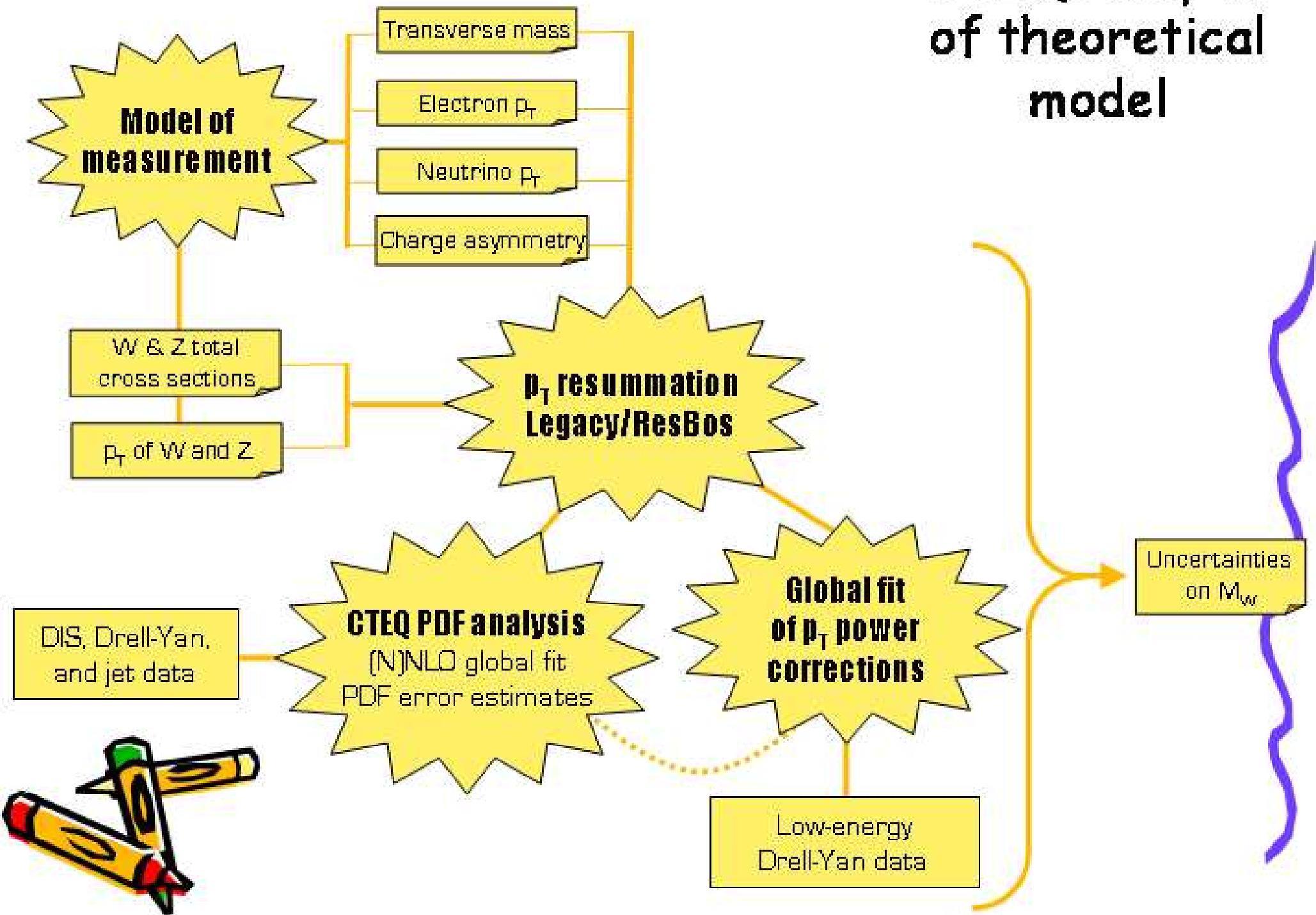
Many sources of sizeable correlated errors

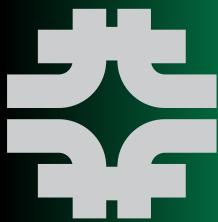


Those systematic errors must be put under control
to measure M_W with accuracy < 50 MeV



CTEQ analysis of theoretical model





Simplified model of experimental measurements

- ✓ Central ($-1 \leq y_e \leq 1$) and forward ($|y_e| > 1$) regions
- ✓ $p_{T e} > 25$ GeV
- ✓ Missing $p_T > 25$ GeV
- ✓ Electron energy smearing
- ✓ ...?



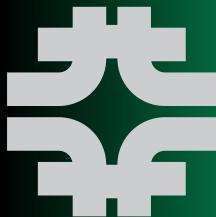
Upgrades (seriously improved resummation software)



Legacy
(EW boson
production)

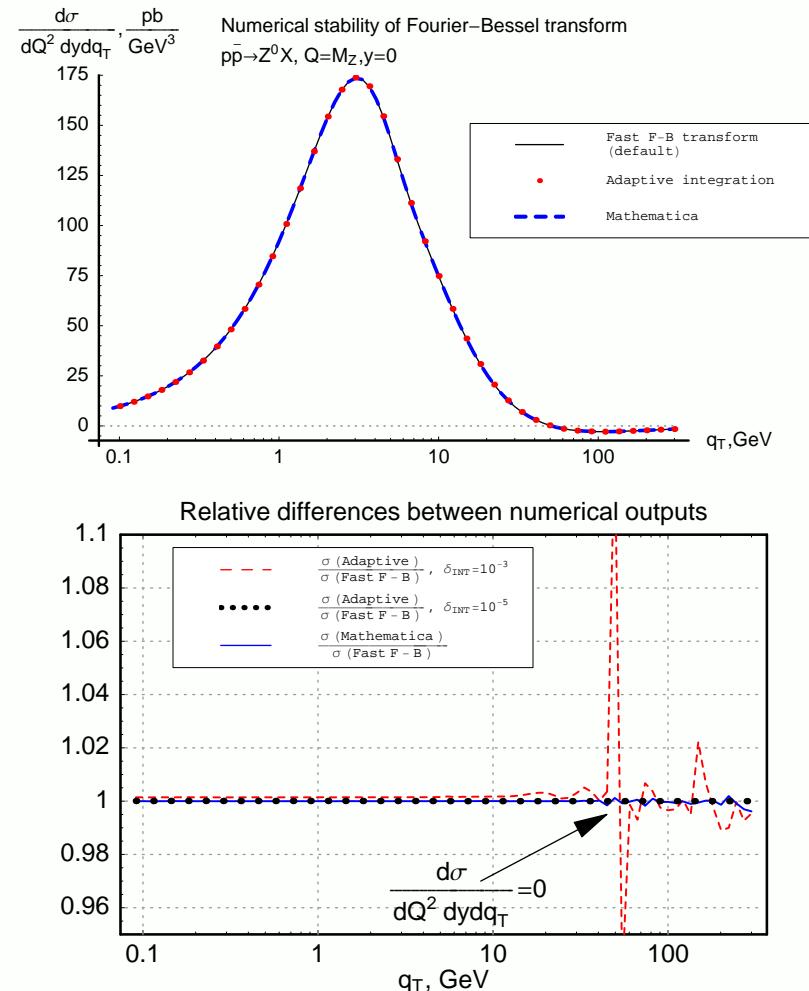
ResBos
(EW boson decay)

Program for
global fit of p_T
distributions

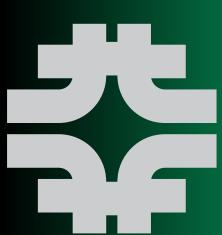


Fast and accurate resummation program

- ✓ Resummation part re-written in C++
- ✓ Adaptive integration and fast Fourier-Bessel transform routines
- ✓ Improvement up to a factor 800 (80000%) in speed
- ✓ Accuracy of F-B transform better than 0.1% at $q_T^2 \ll M_W^2$



Suitable for intensive CPU calculations within the CTEQ fitting analysis



Universality of resummed q_T distributions in $h_1 h_2 \rightarrow V X$

(Landry, Brock, P.N., Yuan, Phys.Rev. D67, 073016 (2003))

As PDF's include the universal nonperturbative part, resummed q_T distributions are expected to include a universal nonperturbative function

$$\frac{d\sigma}{dx_1 dx_2 dq_T^2} \Big|_{q_T \rightarrow 0} \propto \int \frac{d^2 b}{(2\pi)^2} e^{i\vec{q}_T \cdot \vec{b}} W^{\text{pert}}(b, x_1, x_2) e^{-S^{NP}(b, Q, x_1, x_2)},$$

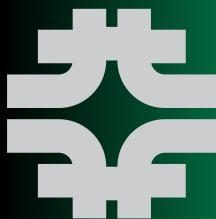
where

$$S^{NP}(b) = b^2 (g_1 + g_2 \ln Q) \quad (\text{Davies, Webber, Stirling, 1985})$$

$$S^{NP}(b) = b^2 (g_1 + g_2 \ln Q) + b g_1 g_3 \ln (100 x_1 x_2) \quad (\text{Ladinsky, Yuan, 1993})$$

$$S^{NP}(b) = b^2 (g_1 + g_2 \ln Q + g_1 g_3 \ln (100 x_1 x_2)) \quad (\text{BLNY, 2002})$$

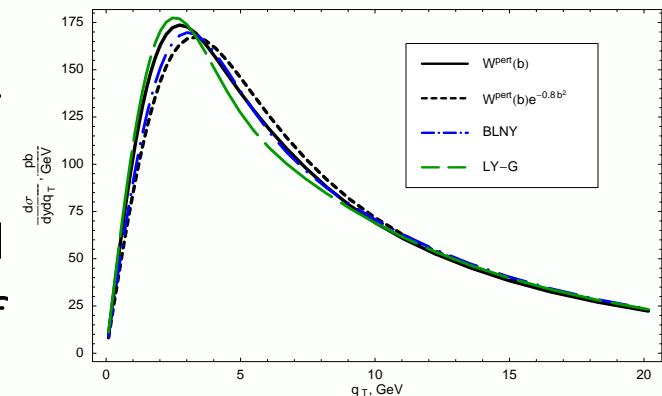
The last form more preferable theoretically (CSS; Korchemsky, Sterman)



Are nonperturbative contributions important for Tevatron?

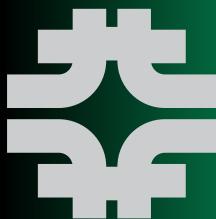
We find strong sensitivity of the Run 1 Z data to $S^{NP}(b)$ at $q_T \lesssim 10$ GeV

Recently, Qiu and Zhang suggested that such dependence may be an artifact of “ b_* prescription” for $S^{NP}(b)$. They suggest that Z data is described well just by the perturbative part of the resummed cross section



While W and Z boson cross sections are dominated by perturbative terms, neglecting (or changing) $S^{NP}(b)$ may shift the peak of $d\sigma/dq_T$ by 200-500 MeV (large effect given a targeted $\delta M_W \sim 50$ MeV)

- ✿ The global analysis of $S^{NP}(b, Q)$ and its Q dependence remains very necessary



Nonperturbative function in the resummation formalism

BLNY study:

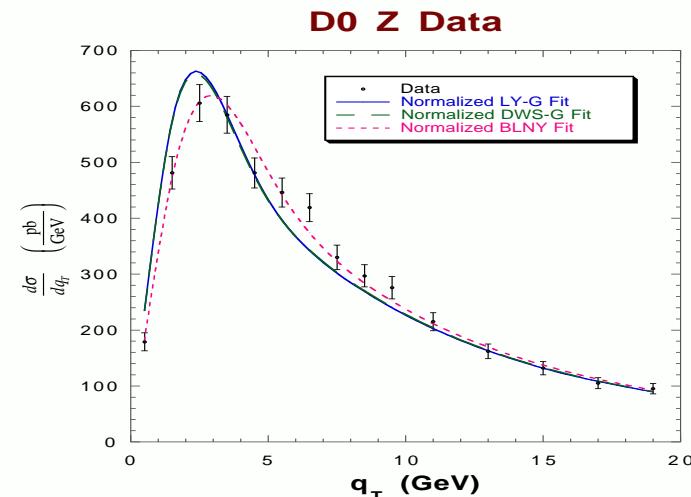
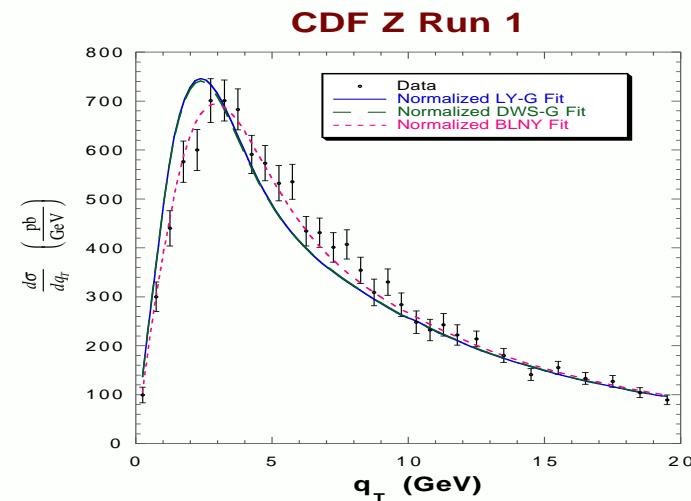
- ✓ first global fit of the Drell-Yan and Tevatron Run 1 Z data

- ✓ extended set of data (~ 100 data points vs. 31 point in earlier studies)

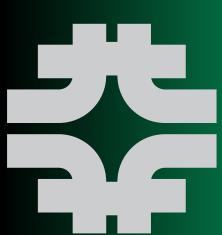
- ✓ All 3 forms of $S^{NP}(b)$ updated

- ✓ Gaussian form (BLNY) strongly preferred by the data;

$\chi^2/d.o.f. = 176/119 \sim 1.48$ vs. 3.42 and 3.47 for other forms

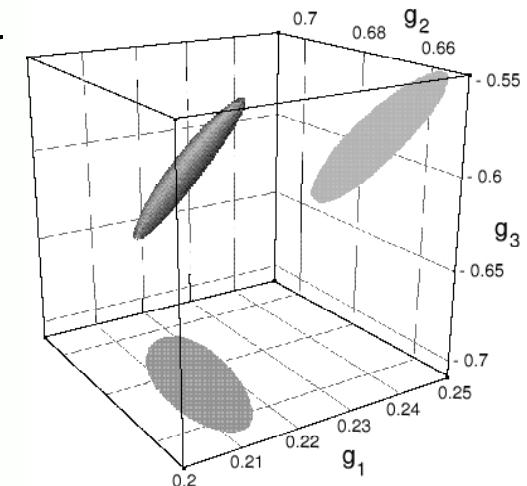


❖ Strong evidence for universality of $S^{NP}(b, Q)$



Nonperturbative contributions: further studies

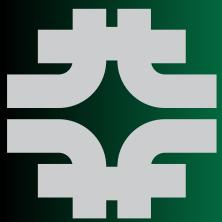
- ✓ Explore new proposals for the model of nonperturbative terms
- ✓ Examine an updated b_* prescription with $b_{max} \sim 1 \text{ GeV}^{-1}$
- ✓ Obtain true confidence intervals for $S^{NP}(b, Q)$ in presence of systematical errors
- ✓ Study correlation between nonperturbative Sudakov factor $S^{NP}(b, Q)$ and parton distributions
 - ◆ Refit $S^{NP}(b, Q)$ for 41 eigenvector PDF sets
 - ◆ Merge global fits of the PDFs and p_T distributions





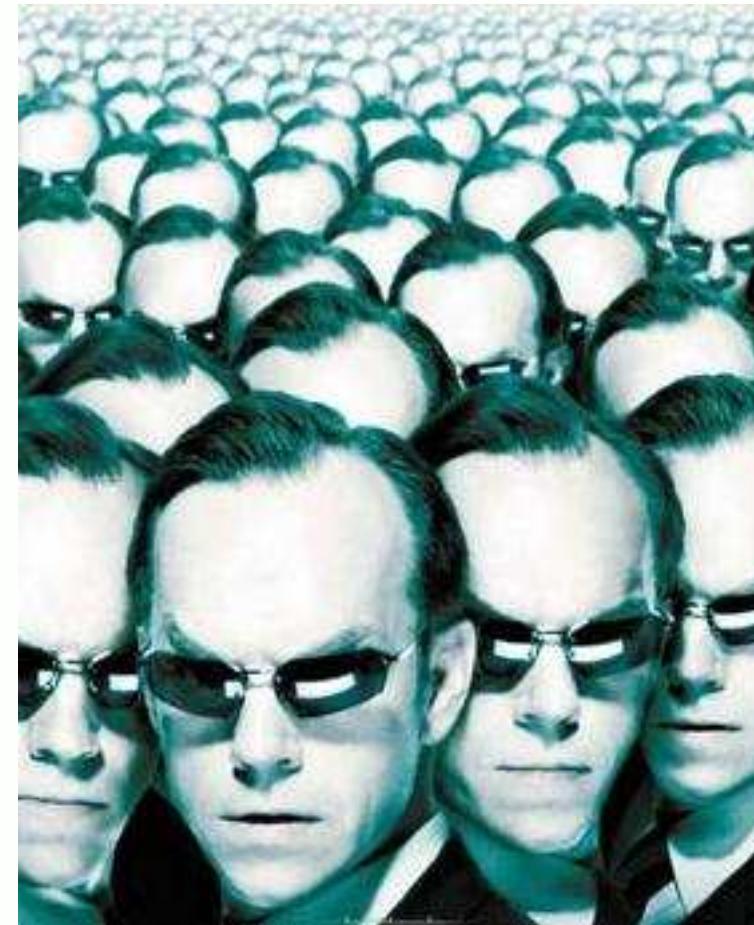
Global analysis (CTEQ)

- ✓ Analysis of a large data set (~ 2000 data points) from deep inelastic scattering, lepton pair and jet production
- ✓ Methods for handling many (~ 200) sources of systematic errors
- ✓ Complete analysis of the PDF parameter space in the vicinity of $\min \chi^2$ with inclusion of all published correlated systematic errors
- ✓ Quantitative estimates of uncertainties in the PDFs and physical observables
 - ◆ Lagrange mutliplier method
 - ◆ 1 central PDF set + 20×2 extreme PDF sets 
 - * Calculate the observable 41 times
 - * Calculate PDF uncertainty using a master formula

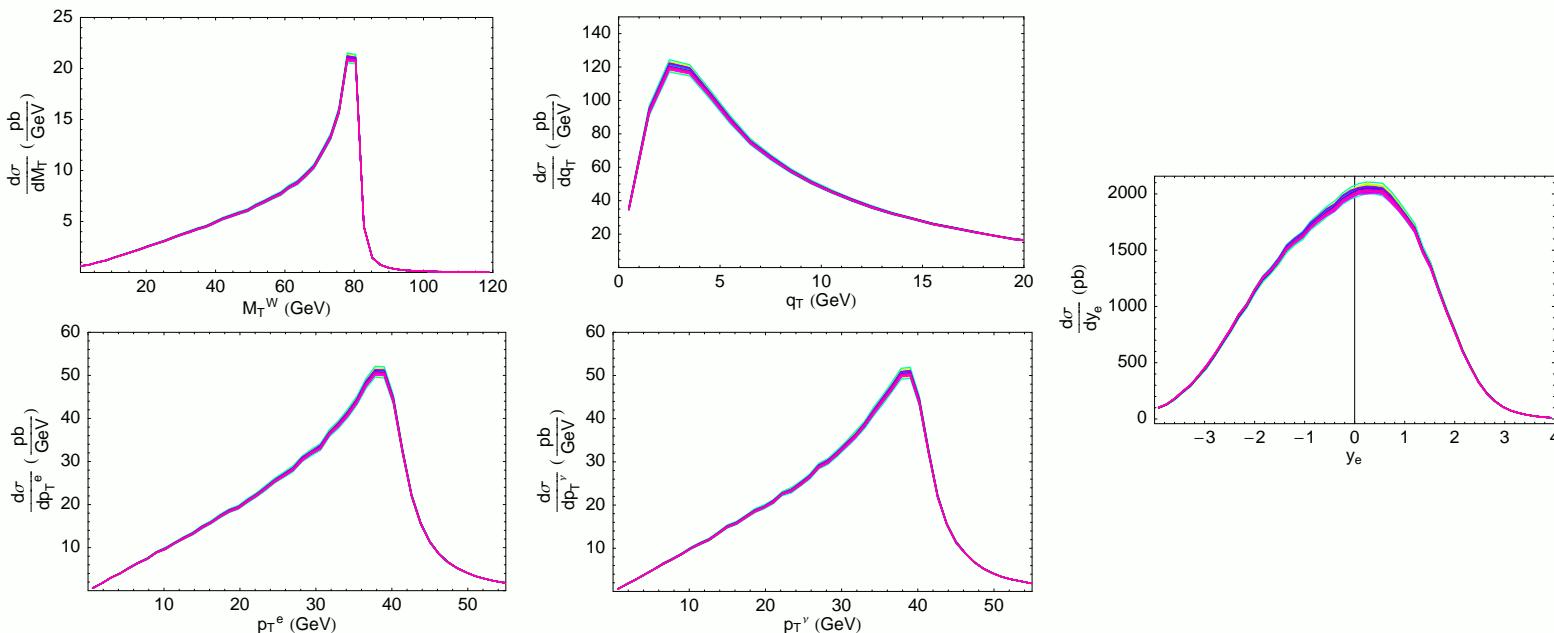


PDF uncertainties, or

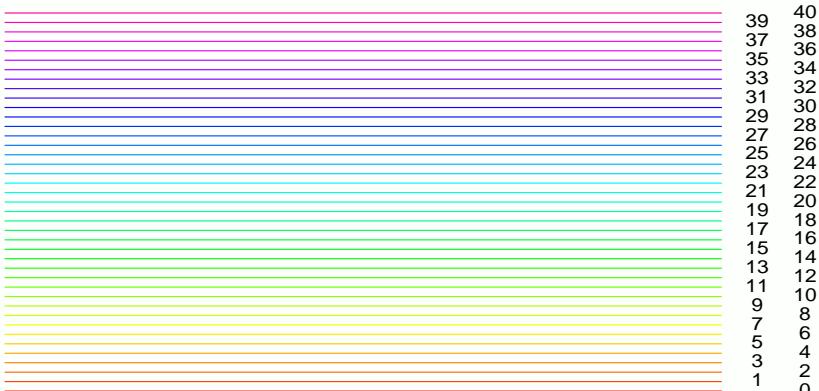
“You have already shown me this plot 40 times!”



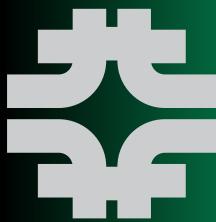
W^+ production at $\sqrt{s} = 1.96$ TeV; $M_W = 80.423$ GeV; no lepton cuts



Color legend for PDF sets



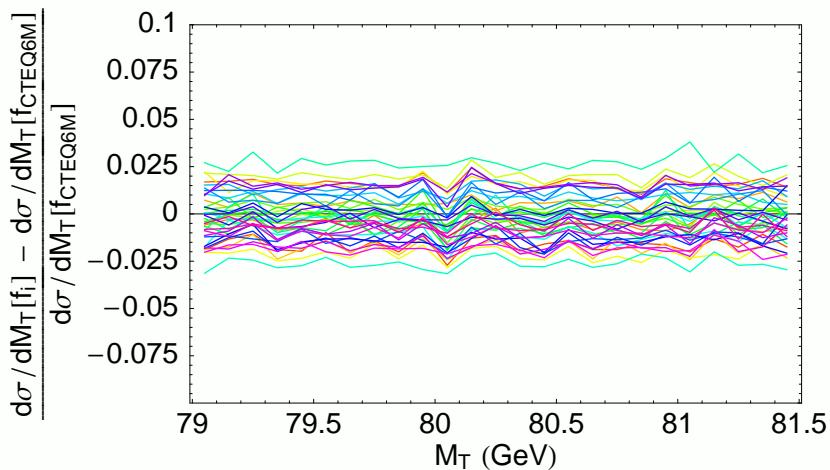
Concentrate on the ratios to
the distribution for CTEQ6M
PDF set instead



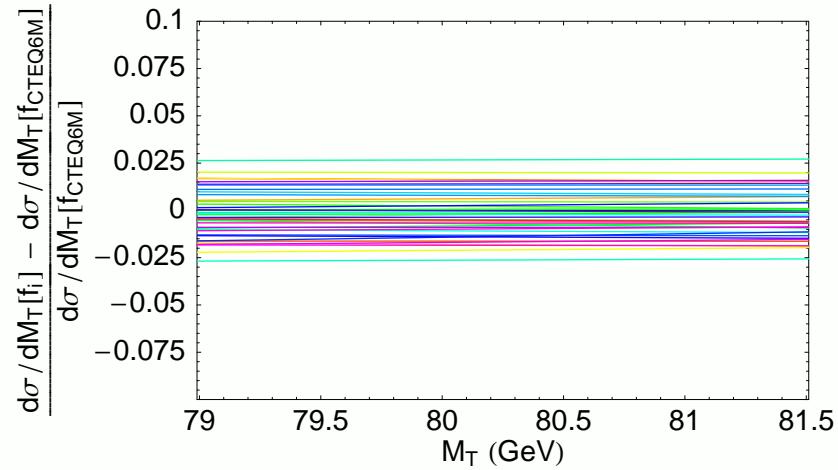
PDF dependence of the ratio for M_T distribution (VERY PRELIMINARY)

Combined W^+ and W^- sample, $-1 \leq y_e \leq 1$, $p_{Te} > 25$ GeV

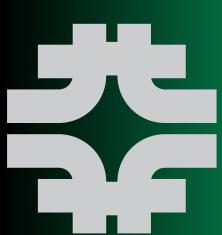
Raw ResBos output



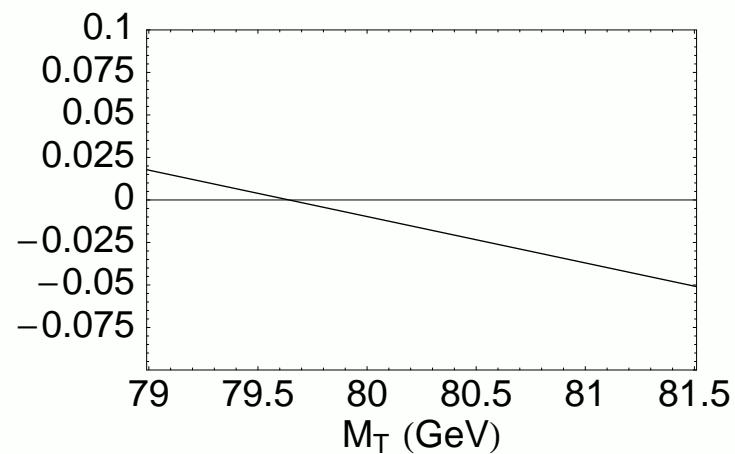
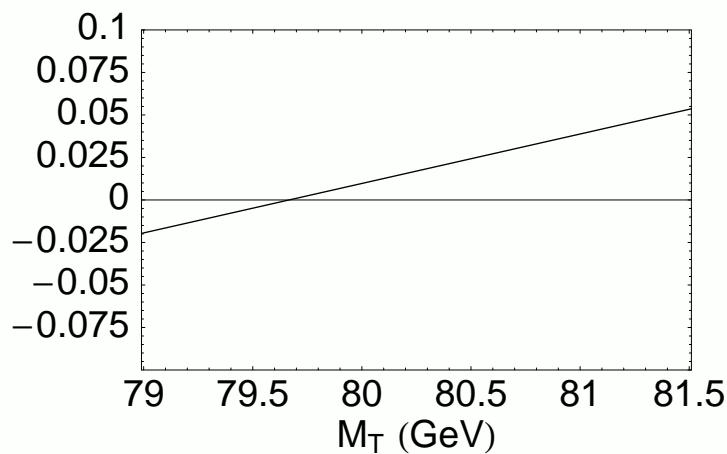
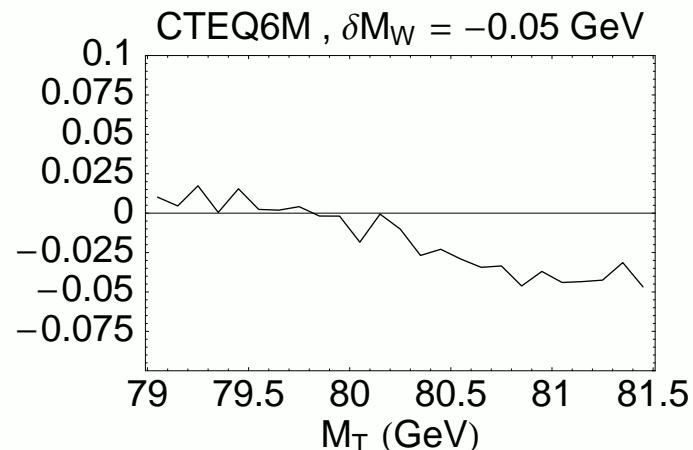
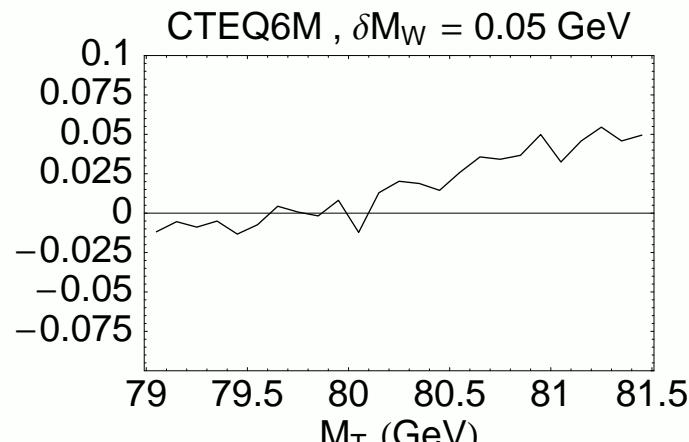
Linear fit



PDF variation changes normalization and not the slope



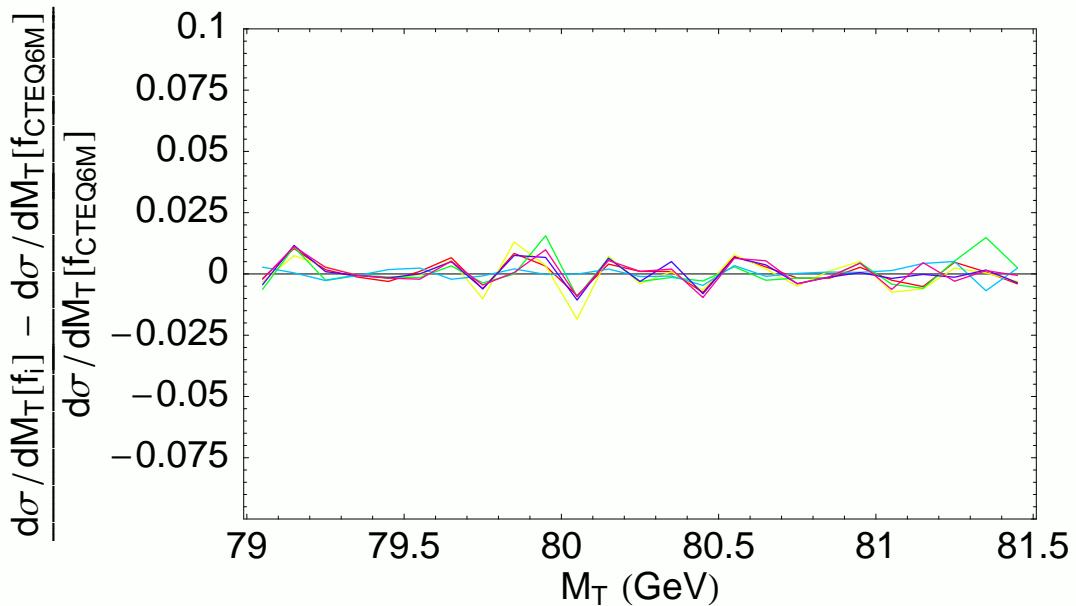
Variation of M_W by $\delta M_W = \pm 50$ MeV (VERY PRELIMINARY)



Visible variation in the slope (corresponding to the shift of the Jacobian peak)

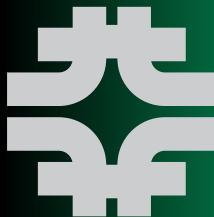
\therefore PDF error on M_W from M_T distribution is much smaller than 50 MeV

Variation of $S^{NP}(b, Q)$ within the 1σ ellipse from the BLNY paper (VERY PRELIMINARY)



No visible change in slope

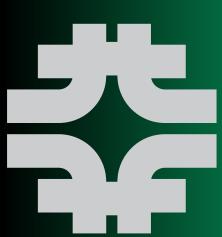
Note: The above error on $S^{NP}(b, Q)$ (for $\delta\chi^2 = 1$) underestimates the true error (dominated by systematic uncertainties)



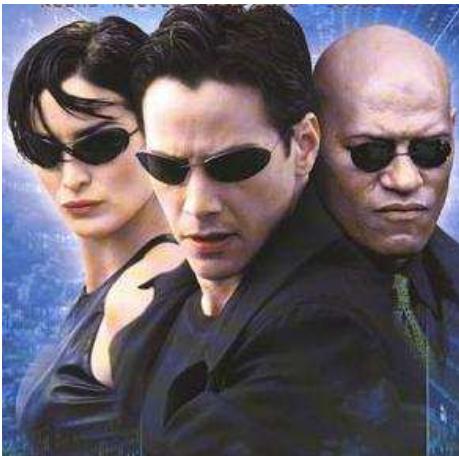
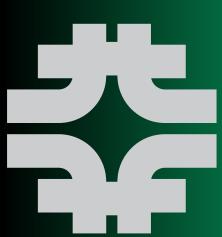
Variations in the slopes of $d\sigma/dM_T$ ratios (VERY PRELIMINARY)

Source	$\delta(\text{Slope})$ (pb/GeV 2)	Comparable δM_W (MeV)	Comments
$\delta M_W = 50$ MeV	0.003	50	
PDF error	0.002	5	$\delta\chi^2(\text{PDF}) = 100$
$\delta S^{NP}(b, Q)$	0.0008	3	$\delta\chi^2(\text{BLNY}) = 4$

Monte-Carlo error is ~ 0.001 (2 MeV)



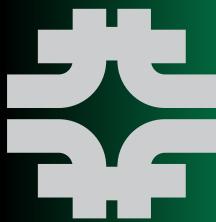
PDF and q_T errors for $\delta M_W(M_T)$ are
of order a few MeV



PDF and q_T errors for $\delta M_W(M_T)$ are
of order a few MeV

PDF and q_T errors for $\delta M_W(p_T^e)$ are
of order tens MeV

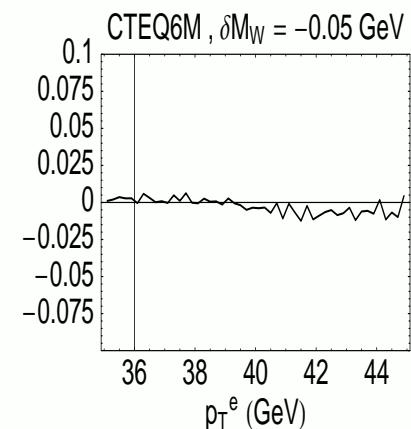
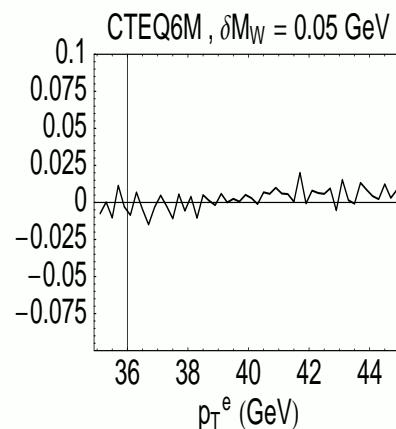
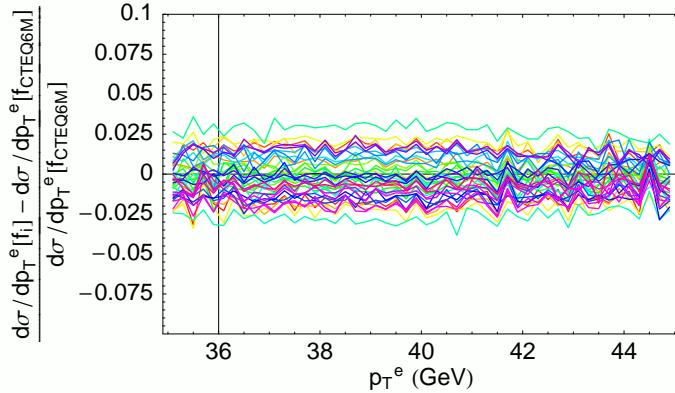




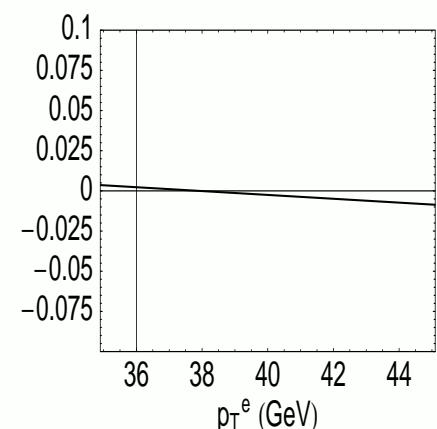
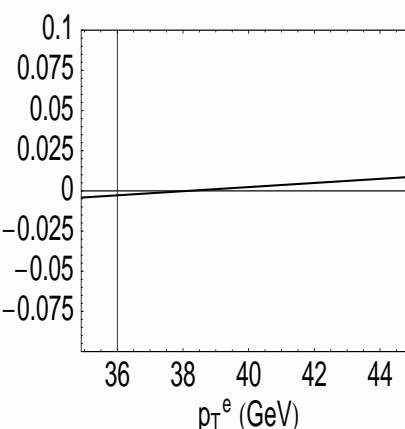
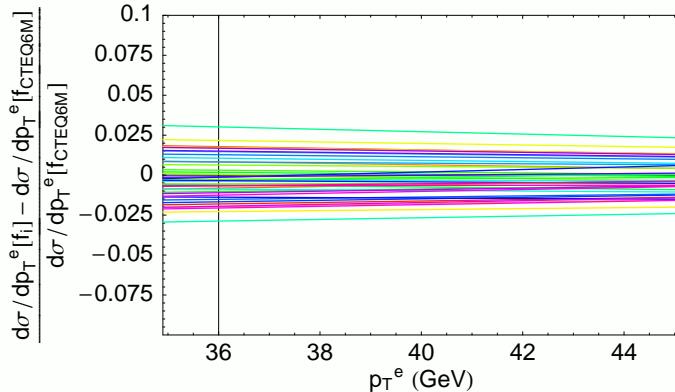
PDF dependence of the ratio for the electron p_T distribution (VERY PRELIMINARY)

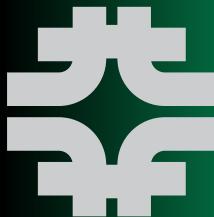
Combined W^+ and W^- sample, $-1 \leq y_e \leq 1$, $p_{Te} > 25$ GeV

ResBos output



Linear fit



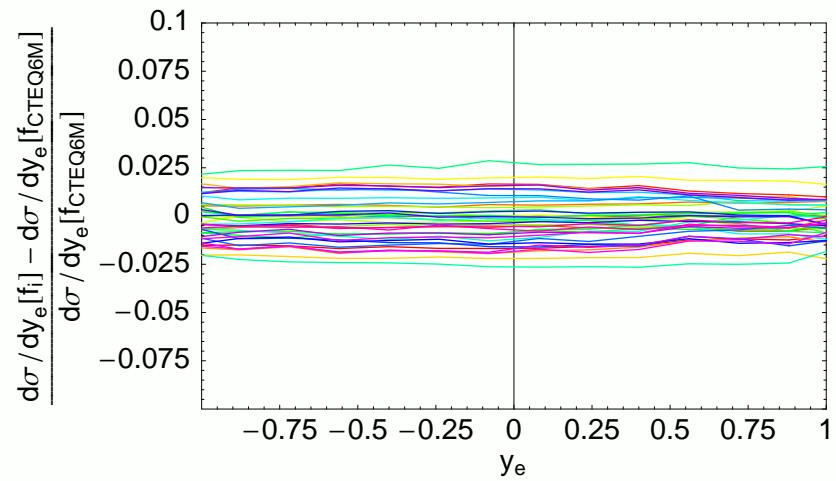
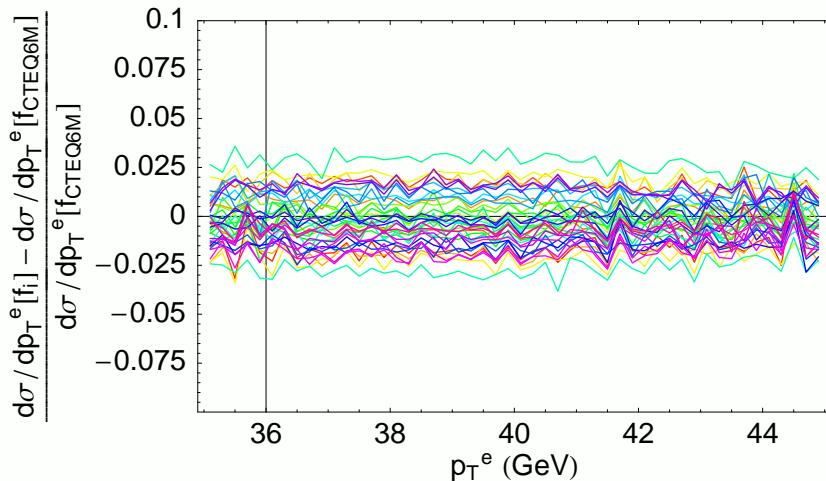


Variations in the slopes of $d\sigma/dM_T$ ratios
(VERY PRELIMINARY)

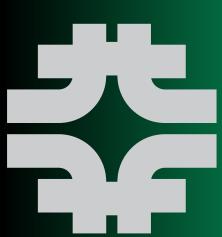
Source	$\delta(\text{Slope})$ (pb/GeV 2)	Comparable δM_W (MeV)	Comments
$\delta M_W = 50$ MeV	0.0012	50	
PDF error	0.0014	60	$\delta\chi^2(\text{PDF}) = 100$
$\delta S^{NP}(b, Q)$	0.0008	30	$\delta\chi^2(\text{BLNY}) = 4$

Monte-Carlo error is ~ 0.00016 (7 MeV)

Correlation between p_T^e and y_e (VERY PRELIMINARY)



Better measurement of charge asymmetry will reduce the PDF error?



Instead of conclusion...

